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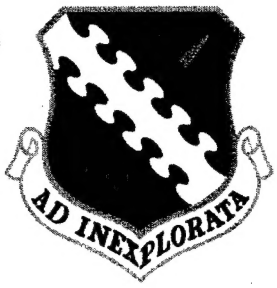

A YEAR OF BOMBER TEST - LEGACY AND LESSONS LEARNED

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14. ABSTRACT The 419th Flight Test Squadron (419 FLTS), located at Edwards Air Force Base, California, is responsible for developmental testing of the B-1B, B-2A, and B-52H aircraft for the US Air Force. The Operations Engineering Flight at the 419 FLTS is comprised of operations engineers, test conductors, and test directors who are responsible for coordinating the efforts of the entire flight test team. Several flight test programs took place on all three airframes over the past year. The B-1B integrated the Joint Standoff Weapon and Joint Air-to-Surface Standoff Missile to the platform. The B-2A completed regression testing to validate the newest software drop and added a new tactical Link-16 terminal that promises to improve pilot situational awareness during combat. The focus of B-52H testing has been upgrading the offensive avionics system to carry the platform to 2037. Lessons learned were documented throughout the three test programs in a never-ending effort to improve flight test safety and efficiency. Communications procedures were standardized between the mission control room, the aircrew, and the range. Ground test planning procedures were adopted to mirror, as much as possible, the rigorous planning required of flight test. Finally, configuration control procedures were implemented to preclude the incorrect integration of test hardware.

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SUMMARY

The 419th Flight Test Squadron (419FLTS), located at Edwards Air Force Base, California, is responsible for developmental testing of the B-1B, B-2A, and B-52H aircraft for the US Air Force. The Operations Engineering Flight at the 419FLTS is comprised of operations engineers, test conductors, and test directors who are responsible for coordinating the efforts of the entire flight test team. The operations engineer begins the flight test mission planning process by translating engineering requirements into cogent test cards. They assign specific test points to a mission objective summary and assemble a notional outline of a prospective test mission. They schedule and deconflict resources and mission requirements. The test conductor then appropriates mission planning activities and acts as the absolute focal point of the mission, ensuring overall quality of the test planning process in the final days leading up to a mission. They conduct the mission readiness review, control the execution of the mission from the control room, and draft the "quicklook report" documenting that particular flight test in detail. The test director (as opposed to the test conductor) acts as the squadron commander's representative during a mission and has absolute authority to cancel a mission at any time at his discretion whenever anything fails to meet standard test criteria, proper test discipline, or violates test safety.

Several flight test programs took place on all three airframes over the past year. The B-1B integrated the Joint Standoff Weapon and Joint Air-to-Surface Standoff Missile to the platform. The B-2A completed regression testing to validate the newest software drop and added a new tactical Link-16 terminal that promises to improve pilot situational awareness during combat. The focus of B-52H testing has been upgrading the offensive avionics system to carry the platform to 2037.

Lessons learned were documented throughout the three test programs in a never-ending effort to improve flight test efficiency. Communications procedures were standardized between the mission control room, the aircrew, and the range. Ground test planning procedures were adopted to mirror, as much as possible, the rigorous planning required of flight test. Finally, configuration control procedures were implemented to preclude the incorrect integration of test hardware.

1.0 INTRODUCTION

The 419th Flight Test Squadron (419FLTS) Edwards Air Force Base, California, is responsible for developmental testing of B-1B, B-2A, and B-52H aircraft for the US Air Force (USAF). A wide range of

testing has taken place on these three airframes whose designs span over 40 years of engineering innovation. Over the past year, the 419FLTS completed a variety of test activities to extend airframe usable life, upgrade combat capabilities, and integrate new weapons across the bomber fleet. By sharing our successes and lessons learned we hope to improve test efficiency and safety within the flight test community.

The primary B-1B test effort, known as "JJI", integrated the new Joint Standoff Weapon (JSOW) and Joint Air-to-Surface Standoff Missile (JASSM) to the platform. The JJI program included both hardware and software upgrades. Lessons learned mainly related to communication. The challenges of communication during periods of high crew workload were overcome through the use of standard phraseology and extensive mission preparation.

During the past year the B-2A has undergone two major flight test efforts, regression testing to validate the newest software drop, and validation testing of a new Link-16 terminal that promises to enhance pilot situational awareness. During these two simultaneous test programs the team re-learned a lesson on the importance of configuration control and also learned that ground testing should be executed with the same rigor as flight testing.

The focus of B-52H testing has been the Avionics Mid-Life Improvement (AMI) program that demonstrated the developmental and operational readiness of an enhanced and upgraded offensive avionics system. This new avionics suite consisted of ring laser gyro inertial navigation units, avionics control units, data transfer, mission planning hardware/software, and new software for the upgraded processors. Many lessons were learned throughout the test program, including: ensuring hardware compatibility prior to testing; requiring a "performance-driven" test philosophy rather than "schedule-driven"; the necessity for active aircrew participation in the mission planning process; the effectiveness of partnerships between developmental and operational personnel; and discrepancy tracking.

2.0 THE FLIGHT TEST PROCESS

This section endeavours to explain the workings of the flight test process from the perspective of flight test engineers at the 419FLTS. The 419FLTS is one of eleven squadrons/directorates/groups in the 412th Test Wing. Both the 419FLTS and the 412th Test Wing are located at the Air Force Flight Test Center, Edwards Air Force Base, California. Our collective mission is "to conduct and support the research, development, test, and evaluation of aerospace systems from concept to combat."

The 419FLTS is the test execution organization responsible for all USAF bomber flight test activities for B-1B, B-2A, and B-52H aircraft. The 419FLTS is mainly concerned with the *developmental testing* (DT) of new or upgraded aircraft systems, software, weapons, etc. Although the focus at the 419FLTS is DT, it works with and shares office space with Air Combat Command and Air Force Operational Test & Evaluation Center testers who are responsible for *operational testing* (OT) of the same systems. DT and OT aircrews fly together on the same test missions. This DT/OT mix is somewhat unique at the Flight Test Center and allows for a more comprehensive evaluation of the system under test—a single evaluation from both the DT and the OT perspectives with their respective priorities. Other participating organizations include the weapon system program office which provides overall programmatic oversight for the test program, one or more contractors who generally provide technical expertise for the system under test, and various other test organizations depending on the requirements of the particular test program.

The Operations Engineering Flight at the 419FLTS is comprised of a team of twelve people—military, civil service, and contractor personnel—who are responsible for the overall coordination of ground and flight test

activities. They serve in various capacities as operations engineers (OEs), test conductors (TCs), or test directors (TDs) and as such they coordinate the efforts of the rest of the flight test team which is comprised of aircrew (pilots, navigators, weapons systems officers, flight test engineers), specialized discipline engineers, maintenance personnel, program managers, instrumentation technicians, range control officers, and mission control room monitors.

2.1 The Role of the Operations Engineer

The role of the OE is to begin the planning process for a flight test mission. Prior to the start of a flight test program, OEs attend programmatic planning meetings to decide upon the general priority and order of the test points to be accomplished throughout the specific flight test program. They take test requirements in the form of test information sheets from the specialized discipline engineers and work with TCs to translate these hard engineering requirements into cogent test cards which the aircrew then will use to execute a test mission. The goal is to have the test cards for the entire flight test program completed one month prior to the first mission so that the aircrew and engineers have sufficient time to review and correct them. Once the draft cards are complete, mission planning for the test program begins in earnest. The OE conducts a weekly mission planning group meeting where mission objective summaries for the next four weeks are outlined. There, the OE works with engineers and aircrew to assign test points to specific missions in an intelligent way in order to maximize mission productivity while observing time constraints, configuration requirements, and resource availability. The OE also hosts another weekly meeting to deconflict resource requirements between the three airframes. It would be unwise, for example, to fly multiple large bombers into the same range at the same time. Two weeks prior to a mission, the OE submits formal requests to schedule the following resources: the test aircraft and its proper test configuration; support aircraft such as air refuelling tankers and photo/chase aircraft; the airspace; range assets; communication and telemetry frequencies; instrumentation requirements; aircrew; and control room personnel. After scheduling is completed, all of the mission information is passed on to the TC who continues the planning process with an eye for detail.

2.2 The Role of the Test Conductor

The TC is the focal point for the mission and is considered the single-point-of-contact for all matters relating to the mission. They are responsible for the final selection and ordering of the test points for the mission, the accuracy of the test cards and resource requests, and the overall coordination of the flight test team. The importance of thorough attention to detail for the job can not be overemphasized because one small oversight can very well cause the cancellation of the mission—an error which can easily amount to hundreds of thousands of dollars in costs—or worse...a safety breach. The TC conducts a mission readiness review meeting on the day prior to the flight. The flight test aircrew, control room personnel, specialized discipline engineers, range control officers, instrumentation personnel, maintenance personnel, program management, and the TD attend this meeting. The test team reviews that particular mission in detail including the mission objectives and test cards. They consider safety of flight issues, general safety minimizing conditions, potential test hazards, and go/no-go criteria. They review weather forecasts, NOTAMs or "notices to airmen", previous missions' discrepancy reports, and watch items. The TC attends a final mission brief on the morning of the flight where any last-minute issues are brought forth and the final decision to proceed is made. The TC then conducts the mission from a specialized mission control room manned with technical experts monitoring real-time data during the flight. All control room issues and requests are filtered through the TC airplane to the aircrew, since the TC is the single voice to the crew on the radio. The TC *controls* the flight test mission. After the mission has been completed and the aircrew has returned, the TC conducts a mission debrief where the following issues are considered: maintenance problems; aircraft performance issues; instrumentation status; summary of test points attempted/completed; a review and discussion of the test; and documentation of

lessons learned during the test. Finally, the TC writes a "quicklook" report to document all of these issues and creates and archives a mission folder containing all of this data.

2.3 The Role of the Test Director

The function of the TD is to ensure that proper flight test discipline is observed at all times with regard to safety, test control, and test conduct. The TD acts as the squadron commander's representative during flight test since it would be impossible for the commander to be in attendance for all possible missions and associated coordination meetings. The TD has the authority to cancel a mission at any time at his discretion whenever anything fails to meet standard test criteria, proper test discipline, or violates test safety. For this reason the TD is always a highly experienced and respected engineer, normally a former or active aircrew member, handpicked by the commander for his/her personal integrity and aura of authority. It is the job of the TD to question any aspect whatsoever of mission planning or execution, to take a step back and have a broad perspective for potential areas of risk, and to challenge the test team if required. The TD grants the authority to proceed with the test at the conclusion of the mission readiness review. The TD conducts the mission brief on the morning of the flight and is in the control room during mission execution to perform test oversight. However, the TD also coordinates air refuelling efforts and photo/safety chase aircraft operations from the control room during the execution phase. After mission completion, the TD documents any lessons learned during the mission.

3.0 THE B-1 TEST PROGRAM

The B-1B was originally envisioned to be a nuclear bomber. But, through the long-term Conventional Mission Upgrade Program (CMUP), the B-1B has gained a significant ability to drop precision and non-precision conventional weapons. These increased capabilities were showcased during the first six months of Operation Enduring Freedom in which the B-1B was responsible for almost 40 percent of the total tonnage dropped [1]. The primary B-1B test effort of 2004 was the JSOW and JASSM Integration (JJI) flight test program, part of the ongoing CMUP program. The purpose of the JJI program was to correct deficiencies identified in prior upgrade programs, add new weapons system capabilities, and increase the B-1B standoff attack capability by integrating the JSOW and JASSM. This involved not only the integration of the new weapons, but also hardware and software upgrades to accommodate the new capabilities [2].

3.1 New Weapons

The AGM-154 Joint Standoff Weapon (JSOW) is a precision, low-cost, modular, unpowered, glide bomb. It is a 1,000-pound class weapon with a 70 nautical mile range. The JSOW offers a modular warhead family with options for unitary blast, sub-munitions, or penetrating warheads [3].

The AGM-158 Joint Air-to-Surface Standoff Missile (JASSM) is a precision, long-range, autonomous, powered missile designed to counter high-value, defended targets. It is a 2,000-pound class weapon with a range greater than 200 nautical miles. The B-1B is capable of carrying 24 JASSMs or 12 JSOWs [4].

3.2 The JJI Test Program

The JJI flight test program had four objectives: to demonstrate successful integration of the JSOW and JASSM onto the B-1B platform, to demonstrate that no degradation to existing aircraft capability occurred due to JJI, to evaluate the military utility of the JSOW and JASSM enhancements to the B-1B aircraft, and to evaluate the B-1B JJI system readiness for operational test and evaluation [2]. Testing began in September 2003 and ended in June 2004 after 34 sorties and 145 flight test hours. A total of six JASSMs were released for this program, four to conduct weapon separation testing and two actual releases. The releases culminated in an all-up-round release of a completely representative missile with live sub-munitions. A total of eight JSOW weapons were released for separation testing with no actual target prosecutions. These developmental flight tests culminated in an important milestone in that the B-1 is currently the only platform capable of re-programming a weapon's route in real-time to send it to a different target. The JASSM and JSOW were satisfactorily integrated onto the B-1B.

Figure 1: JSOW Drop at Edwards AFB (USAF Photo)

Part of the program objectives required that JJI would not cause degradation to existing aircraft capability. This required extensive regression testing of many of the B-1B's systems including terrain following, radar, navigation, and previously integrated weapons. At the end of the program, all four objectives were satisfactorily accomplished and the system was certified for operational testing.

4.0 THE B-2 TEST PROGRAM

The B-2A is a long-range strategic bomber designed to penetrate hostile airspace and deliver weapons with minimal detection by the enemy. The aircraft is a four-engine flying-wing design incorporating advanced technology to reduce radar cross section, infrared signature, visual acquisition, acoustical noise, and electromagnetic radiation. It is operated by a two-person crew and can carry up to 50,000 pounds of payload with a maximum gross takeoff weight of 330,000 pounds. It has a mission completion rate of 45 percent [5]. Two flight test programs took place concurrently from March through December 2004. The first was the integration of a tactical data link system called Link-16, which promises to improve aircrew situational awareness during combat, and the second was a scheduled upgrade to avionics software production development version four (PD-4.0).

4.1 Link-16

The purpose of the tactical data link system known as Link-16 was to "exchange real-time tactical data among military units" while incorporating "nodelessness, jam resistance, flexibility of communications, separate transmissions, data security, the ability to serve a large number of participants, high data capacity, various network navigation features, and secure voice" [6]. The B-2A was the first USAF bomber to integrate Link-16.

The B-2A Link-16 flight test program integrated and demonstrated a Link-16 multifunction information distribution system (MIDS) low volume terminal, a center instrument display set (CIDS), and an enhanced in-flight replanner (IFR) on the B-2A. These communications, display, and IFR capability upgrades provided a theatre-wide connectivity capability to up-link, display, and process real-time and near real-time command and control data. The Link-16 system provided tactical data information at high rates among land, surface, and airborne units by distributing encrypted, jam resistant information securely and with high-reliability in a hostile environment. Primary functions included the exchange of friendly unit position and status data, dissemination of tactical surveillance track data, and the control and management of air and surface engagements. The system required installation of two new antenna interfaces on the B-2A [6].

Figure 2: B-2 JDAM Release Test

The overall goal of the B-2A Link-16 flight test effort was to assess the system performance and military utility resulting from the integration of Link-16, the CIDS software and hardware, and in-flight re-planner modifications. The combined Link-16/PD-4.0 flight test program consisted of 144 ground test hours and 29 missions for 115 flight test hours.

4.2 Software Upgrade PD-4.0

A second B-2A flight test program validated a new avionics software version and it ran concurrently with the Link-16 flight test effort. The integrated functional capability production development version 4.0 (IFC PD-4.0) software maintenance program provided corrections to deficiencies found in previous software versions and also incorporated various software and hardware enhancements. The IFC PD-4.0 software comprised the fourth update to the production Block 30 aircraft. It provided new logic capability required for the Link-16 installation, a new center instrument display in the cockpit, in-flight replan capabilities, and general software maintenance.

5.0 THE B-52 TEST PROGRAM

The venerable B-52H Stratofortress, first flown in 1952, remains the USAF's most cost-effective and versatile bomber. Its mission capable rate of approximately 75 percent are the highest of the three bombers and it can carry the widest variety of weapons [8]. For example, it is the only bomber capable of delivering the Conventional Air Launched Cruise Missile (CALCM). The B-52H is the workhorse of the bomber fleet. Although it flew only 4 percent of the combat sorties over Afghanistan and 3 percent of the sorties over Iraq thus far, it accounts for 28 to 29 percent of the total tonnage of weapons dropped in those two conflicts, respectively.

5.1 Avionics Mid-Life Improvement

The B-52H, nicknamed the "BUFF," currently is slated to perform its global mission until the year 2037 at which time it will be an unprecedented 85 years old. Various upgrades and sustainment efforts are underway

to ensure that it will maintain its mission readiness for the next three-plus decades. The Avionics Mid-Life Improvement (AMI) program is one such program intended to keep the BUFF operationally viable.

The AMI test program "developed, installed, and tested an upgraded offensive avionics system (OAS) and replaced the inertial navigation system, avionics control unit, data transfer units, and all associated hardware and software" [9]. Software upgrades were a significant part of the AMI test program and involved: re-hosting the flight management system (FMS) software; reprogramming the stores management overlays (SMOs) for each weapon employed; developing separate aircraft and weapon simulation software for the System Integration Laboratory and the Avionics Integration Support Facility; and finally developing common stores processing software. The flight test effort consisted of 81 test missions over 18 months for 512 flight test hours.

The responsible test organization for the AMI test program was the 419FLTS. The Boeing Company was the AMI contractor and provided technical expertise as well as aircrew members. Overall program management was provided by the B-52H Weapon System Program Office located at the Oklahoma City Air Logistics Center, Tinker Air Force Base, Oklahoma City, Oklahoma. The 49th Test and Evaluation Squadron at Barksdale Air Force Base, Shreveport, Louisiana, augmented the test team.

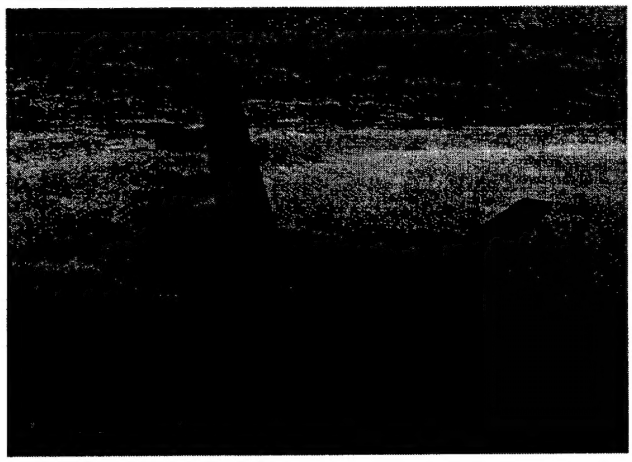

Figure 3: B-52 Over the Rogers "Dry" Lakebed

The past year of AMI flight testing was mainly concerned with validating the FMS in various different navigation modes and ensuring the correct integration of conventional gravity weapons including the Mark-82 500-pound dumb bomb and the Cluster Bomb Unit weapons (CBU-87, -89, -97). Additionally, the integration of the Joint Direct Attack Munition (JDAM), the JSOW, the JASSM, the Advanced Cruise Missile (ACM), and both the conventional and nuclear Air Launched Cruise Missiles (CALCM/ALCM) were tested. Finally, an investigation was performed to characterize the interaction of the FMS and radar cross hairs at the navigator's station.

6.0 LESSONS LEARNED

Many of the lessons learned during flight testing appear obvious in retrospect. Some of them are simply proper testing practice, the kinds of concepts taught at test pilot schools around the world. Whether new lessons, or lessons re-learned, our goal at the 419FLTS is to "cross-pollinate" these lessons across all three bomber airframes so that our planning process becomes more robust. It is our hope that by sharing these lessons with the flight test community, similar mistakes may be avoided and test efficiency improved. What follows is a selection of lessons learned during flight tests of each of the three USAF bomber platforms.

6.1 Effective Communication is the Key to Successful Flight Test

Flying weapons release missions over a test range requires precise timing and specific clearances from both air traffic control and the mission control room. Consequently, the aircrew can quickly become task saturated. Because of these constraints and problems during "hot" in-bound passes, the team strived to optimize the

execution of weapons testing. Many of the weapons drops occurred at our sister range, the Naval Air Warfare Center Weapons Division (NAWCWD) at China Lake, California. Working with NAWCWD added an additional layer of communications to an already comm-intensive situation. The NAWCWD range controller requested that the 419FLTS mission control team keep radio traffic off of the primary mission frequency so that the controller could monitor the range safety aspects of the mission. Therefore, a procedure evolved to utilize the two B-1B radios in parallel, one to talk to range safety at NAWCWD and the other to coordinate with mission control at Edwards. There were problems with managing the volume of radio traffic as well as the nature of the calls. These issues were solved with standard event calls and weapons release timeline rules. A standard bomb communications card was created to implement these rules. It clearly documented speaking roles of various personnel along with the timing and execution of the various clearances required before proceeding to weapon release. This standard also limited communications to mission critical calls during the last 60 seconds of the bomb run when the aircrew was busiest. The team also implemented a set of standard calls for anomalous events. "Skip it, skip it, skip it" was reserved to abort a pass and "knock it off" was reserved for safety of flight issues. Prior to the adoption of this communication standard many of these calls were informally implemented by the 419FLTS test conductors. However, now that they have been standardized, they are briefed before every mission. A final measure to improve communication has been to step through the weapons drop test cards in a "dress rehearsal" during the card review. Each player is now responsible for reading his or her part. These dress rehearsals have paid dividends by eliminating confusion during the final minutes of a complicated and expensive weapons test.

6.2 Treat Ground Testing Like Flight Testing

It is well known that there is no adequate replacement for rigorous and methodical flight test. However, good rules for flight test must not be abandoned when conducting ground tests. During B-2A ground tests, several of the key coordination steps were skipped because it was "only ground test." On many occasions, a day-prior mission readiness review was not performed. The result was an unorganized and inefficient ground test. As previously discussed in section 2.0 of this paper, the Operations Engineering Flight is the keeper of the test planning process. However, the Operations Engineering Flight had not been involved in many of the ground test activities. Improving ground test planning has required educating the specialized discipline engineers and making them the owners of the ground test preparation process. Efforts have been put into place to document, plan, and prepare for ground tests as assiduously as flight test missions.

6.3 Planning to Un-Test

For many test programs, aircraft modifications are required in order to support the test program. For example, special instrumentation might be installed to record specific flight test parameters. When modifications such as these are made, strict configuration control must be maintained to ensure that the temporary changes are removed at the end of the program. In September 2004, a B-2A weapons drop was unsuccessful. The weapon never received the drop command and was retained by the aircraft. The problem was traced to a modified Military-Standard-1760 "smart weapon" umbilical cord. During the investigation, it was revealed that in 1999, 14 umbilicals were modified by removing an electrical connector pin. The pin removal was to ensure that a drop command was not received by a weapon due to unproven flight software. The software had since been validated and released for use, which made the altered umbilicals no longer necessary. Unfortunately, the modified umbilicals were retained in the inventory. In fact, one of these same cables was blamed for another failed weapons test! The cables still remain in the inventory, but now they have been marked "Do Not Use for Flight" and all the weapons technicians have been instructed on their use for training only. This was a particularly embarrassing lesson to learn, but the problem is fixed for future test programs.

7.0 CONCLUSION

In 2004, the 419th Flight Test Squadron flew 194 sorties for a total of 708 flight test hours to sustain and upgrade the US Air Force bomber fleet. These upgrades enable all three platforms to better execute their rapidly changing missions in a changing world. Some unique aspects of the Global Power Bomber Combined Test Force help us accomplish our mission. We are not only co-located with our operational test force, but on test missions we fly with mixed crews of developmental and operational testers. The Air Force has recognized the value of combined testing and placed seamless DT/OT within a new single Air Force Instruction. The Operations Engineering Flight, comprised of operations engineers, test conductors, and test directors, is responsible for test execution across all three bombers. This breadth enables efficient execution of the time-varying demands of multiple programs and also allows for the standardization of processes and procedures across the B-1B, B-2A, and B-52H airframes. Most importantly, it empowers the Operations Engineering Flight to institutionalize best practices and lessons learned between airframes and across programs. It is our recommendation that other test organizations embrace the integrated DT/OT testing methodology and the concept of a single operations engineering flight that has served the Global Power Bomber Combined Test Force so well.

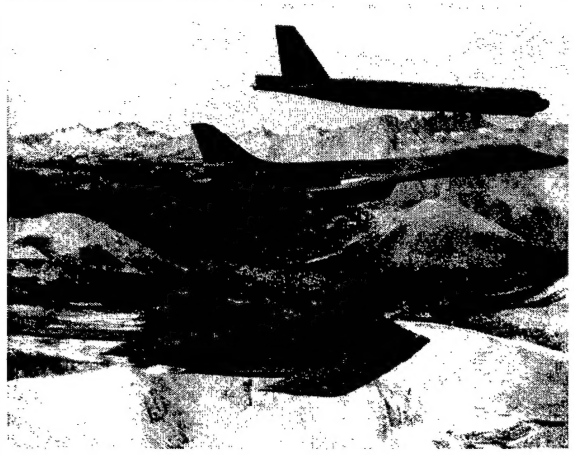

Figure 2: 419FLTS Bomber Trio

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9.0 ACRONYM LIST

ALCM – Air Launched Cruise Missile

AMI – Avionics Mid-Life Improvement

BUFF – Big Ugly Fat Fellow

CALCM – Conventional Air Launched Cruise Missile

CIDS – Center Instrument Display Set

CMUP – Conventional Mission Upgrade Program

DT – Developmental Test

FLTS – Flight Test Squadron

FMS – Flight Management System

IFC – Integrated Functional Capability

IFR – In-Flight Replanner

JASSM – Joint Air-to-Surface Standoff Missile

JDAM – Joint Direct Attack Munition

JJI – Joint Air-to-Surface Standoff Missile / Joint Standoff Weapon Integration

JSOW – Joint Standoff Weapon

MIDS - Multifunction Information Distribution System

NAWCWD – Naval Air Warfare Center Weapons Division

NOTAMS - Notices to Airmen

OAS – Offensive Avionics System

OE – Operations Engineer

OT – Operational Test

PD – Production Development

SMO – Stores Management Overlay

TC – Test Conductor

TD – Test Director

USAF – United States Air Force